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ABSTRACT

A cognitive gap between students' development and school curriculum may be one of the reasons why chemistry is difficult for high school students. This study examined cognitive development in the effect of modified instructional methods for students at the concrete stage of development. The Arlin Test of Formal Reasoning (ATFR) was used for measuring the students' stages of cognitive development. The ATFR results were reported by sex, course, and grade level. Fifty-four percent of the students were functioning at the formal operations stage. One unit, "Liquids and Solids," was selected and taught with diagrams and explanation sheets. Results indicated a positive impact of the modified methods. Appendices included are: (1) "Characteristics of Concrete Level Students"; (2) "Checklist for Content Anaylsis"; (3) "Explanation Sheet"; (4) "Example Problems"; (5) "Work Sheet"; and (6) "Student Evaluation Sheet of Unit/Chapter." (YP)

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# Identifying and Meeting the Needs of Students Functioning at The Concrete Operations Stage of Cognitive Development in the General Chemistry Classroom

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June 1989

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# CHAPTER ONE

# INTRODUCTION

## FOCUS

Some beginning chemistry students expend much effort in solving chemistry problems without being able to grasp the concepts, while other beginning chemistry students grasp the concepts at a much faster rate. Current research indicates that those students who try hard and still have difficulties may not yet have achieved the stage of cognitive development necessary to understand the problems in the form that they are presented by their instructor (Beistel, 1975; Herron, 1975). Additionally, research indicates that the gap between students' low cognitive development and complex problems that are presented by the instructor may be narrowed or eliminated by two modifications of the way the course is currently taught: 1) instructors can present the complex material in less complex ways, and 2) instructors can encourage students to reach higher stages of cognitive development through the types of questions they ask (Beistel, 1975; Herron, 1975).

In this study, changes were made in the instruction (not the overall content) of a portion of a high school chemistry course in an effort to better match the stage of cognitive development of most of the students enrolled in the course.

The responses of the students and the instructor were noted as they progressed through the changes in an effort to determine the degree of satisfaction they all experienced and whether further changes should be made in the course in the future.

RATIONALE

As a high school chemistry teacher, I have at times been puzzled by those students who try hard, come in for extra help, and still do not seem to be able to comprehend the concepts I present to them. It occurred to me that perhaps the level at which I presented the material to such students was inconsistent with their current degree of cognitive development. Thus, there appeared to be a gap between the cognitive stage of the student and the cognitive stage of the problems in these cases.

Jean Piaget (1896-1980) categorized the development of intelligence of humans into four main stages (Weyant, 1987):

1) **Sensorimotor Period** (birth to approximately two years) Children obtain basic knowledge of objects through their senses.

2) **Preoperational** (approximately two to seven years) Children develop skills such as language and drawing ability

3) Concrete Operations (approximately seven to eleven years) Children begin logical thinking (organize knowledge, classify objects, do thought problems).
4) Commencement of Formal Operations (approximately eleven to fifteen years) Children begin to deal with abstractions (ideas about qualities and characteristics viewed apart from objects that have them).

Throughout this research project, "cognitive development" signifies the intellectual development of a student according to Piaget.

When students attend chemistry courses, the course is often presented at the formal operations stage (many abstractions with few concrete connections for the student), while up to 50% of the students may not yet be able to function at that stage (Herron,1975). As a result, students have difficulty, become frustrated, and either fail or drop out. These negative side-effects can be diminished or avoided if the instructor supports the new material with concrete examples (such as visual props and real examples) the students can understand. Furthermore, instructors can show such students how to deal with and organize abstract ideas and thus spur them on to continued formal operational development (Herron, 1975).

This study was an attempt to reduce this gap by more closely matching the cognitive stage of those students struggling in the course. If successful, it was hoped that the students would find that time spent in the class was worthwhile and I, the instructor, would feel satisfied that I was able to "reach" more of my students.

## RESEARCH DESIGN AND METHODS

Following an analysis of the ways I currently taught the general chemistry course at my high school, I compared my teaching methods to the suggestions of current literature in an effort to see how well my current instructional practices met the cognitive stages and problem solving abilities of my students. After attempting to modify the presentation of a chemistry unit in accordance with the literature, I taught the unit to all of my students.

I collected data by two principle means:

1) Before modifying the course presentation, I tested all students presently enrolled in chemistry courses at the high school with the Arlin Test of Formal Reasoning, a test designed to provide the instructor with an indication of the stage of cognitive development a given student may be functioning at. I wished to know how the stages of cognitive development of all students enrolled in the chemistry

courses at my high school compared to that of the students described in the literature.

2) Following modification of the course presentation, all of my students were asked to anonymously complete a Unit Evaluation sheet designed to determine how well the students felt the course met their stage of cognitive development.

The results obtained from the Arlin Test of Formal Reasoning and the students' evaluation sheets, as well as general observations I made were used to determine if further improvements could be made in the unit, and if such modifications should be applied to other units in the future.

# CHAPTER TWO

# REVIEW OF THE LITERATURE

## Introduction

Much has been written regarding efforts that should be made by high school chemistry instructors to match the teaching style used in their course to the stage of cognitive development of their students. If carried out correctly, such actions should aid the students in comprehending the concepts in the course. If the instructor is able to promote further cognitive development in the students as well, then the students should find increased success as problem solvers. This chapter is a review of some of the literature available regarding these topics.

## Why Chemistry Can Be Difficult for Some Students

Piaget's Stages of Cognitive Development have been used as a a reference point for why high school and college level general chemistry coursework can be almost impossible for many students (Herron, 1975; Smith, 1978). Jean Piaget (1896-1980) categorized the development of intelligence in humans, hereafter referred to as cognitive development, into four main stages intended to form a continuum (Weyant, 1987):

1) Sensorimotor Period (birth to approximately two years) Children obtain basic knowledge of objects through their senses.

2) Preoperational (approximately two to seven years) Children develop skills such as language and drawing ability

3) Concrete Operations (approximately seven to eleven years) Children begin logical thinking (organize knowledge, classify objects, do thought problems).

4) Commencement of Formal Operations (approximately eleven to fifteen years) Children begin to deal with abstractions (ideas about qualities and characteristics viewed apart from objects that have them).

Because chemistry often deals with the structure of matter at a level that cannot be observed by students directly, many chemistry courses convey the information to students using formal operations concepts; i.e., the students must be able to conceptualize and theorize in order to fully comprehend. Herron (1975) summarizes this idea by explaining that chemistry is inherently formal by its very nature, regardless of grade level or focus presented. While the concepts in chemistry courses may be best understood by individuals functioning consistantly at the formal operations stage of cognitive development, an individual still functioning at the concrete operations stage is only

able to deal with the content of the problem rather than the relations within it, and is therefore at a distinct disadvantage (Beistel, 1975; Herron, 1975; Smith, 1978).

Several studies have been done on the predicament such beginning chemistry students find themselves in when their stage of cognitive development is disadvantageously matched to the stage at which the course is presented. Most nationally available chemistry curriculum materials assume that students have reached Piaget's formal operational stage (Smith, 1978). However, Chiappetta (cited in Smith, 1978) found that approximately fifty percent of high school students are not able to use formal thought processes. While teaching chemistry at the high school level, Smith (1978) has found that at least half of her students are unable to understand such concepts as atomic structure, moles, polar and nonpolar bonds, and the periodic law, despite diligent effort. Herron (1975) has noticed such chemistry students as well, and explains that they often resort to memorizing what they can but have such poor comprehension of the concepts that they cannot apply them to any problems different from the ones worked out in class. In additon, Mettes, Pilot, Roossink, & Kramers-Pals (1980) have found that these same types of students often have little perspective in approaching problem solving. Herron (1975) prefers to describe their misconceptions as

"no-conceptions" in order to better convey the situation these chemistry students are struggling through.

When considering Piaget's theory of cognitive development and the beginning chemistry student, studies therefore indicate that the students are either at Piaget's stage three (concrete operations) or at stage four (formal operations). However, fifty percent or more of the chemistry students may still be at stage three while the balance are at stage four. The studies add that simply being older than fifteen years of age does not guarantee that an individual's cognitive development is consistantly at stage four, as Piaget once thought (Beistel, 1975; Herron, 1975; Smith, 1978).

Even high school graduates are not necessarily functioning at the formal operations level of cognitive development. Joe W. McKinnon and John W. Renner (cited in Herron, 1975) reported on a study done regarding the stages of cognitive development of typical college freshmen at the University of Oklahoma. They indicated that 50% of the college freshmen tested were still functioning largely at the concrete operations stage, and that only 25% of the sample were functioning fully at the formal operations stage. (The reference did not elaborate on the abilities of the remaining 25% of the sample.)

In conclusion, chemistry, a course that is inherently formal by its very nature, is often taught to a majority of students that are not yet able to function at the formal operations stage. Because roughly half of the students are likely to be functioning at the concrete operations stage and half of the students at the formal operations stage, being cognizant of the sometimes vast differences in abilities of cognitive functioning at each stage should be most important to chemistry instructors if they intend to provide maximum educational benefit to their students. Therefore, characteristics of students functioning at the concrete operations stage will now be compared to the characteristics of students functioning at the formal operations stage. A later discussion will present suggestions for adapting course instruction to better meet the needs of those chemistry students functionong at the concrete operations level.

## Characteristics of Students Functioning at the Concrete and Formal Operational Stages

Students functioning at the concrete operational stage have been found to have cognitive characteristics quite different from those students functioning at the formal operational stage. First, the characteristics of the two stages will be examined with reference to the typical student in general.

Then the characteristics of the two stages will be examined with reference to chemistry students in particular.

Typical students functioning at the concrete operations stage of cognitive development:

> don't know how to conceptualize and theorize;
> deal with content rather than the relationships within the concept (Beistel, 1975);
> must start with the real rather than the potential;
> tend to solve a problem by trial and error; and
> best comprehend concepts which can be observed by the senses directly (Herron, 1975).

On the other hand, typical students functioning at the formal operations stage :

> comprehend through imagination or logical thought;
> are able to envision all changes that might be possible;
> are able to reason without needing visual props;
> can systematically consider all possibilities in a situation;
> are able to control variables in problem solving;
> often revert to concrete stage thinking when encountering unfamiliar concepts (Herron, 1975).

Based on Herron's (1975) judgement of the mental activity required to perform tasks commonly presented in chemistry, the chart found in Appendix 1 was devised. It provides numerous examples of the the cognitive abilities of the chemistry student functioning at the concrete operations stage compared to the chemistry student functioning at the formal operational stage. The tasks have not been formally tested, however.

One of the statements in Appendix 1 points out that students functioning at the concrete operations level can make inferences that are direct extrapolations from observation. They cannot, however, make inferences that are twice removed from observations (if A=B, and B=C, then A=C), as students functioning at the formal operations level can. Another example states that students functioning at the concrete operations level can conceive of acids as any substances that turn litmus paper red. However, they cannot concieve of acids as proton donors or electron pair acceptors, while those students functioning at the formal operations level can (Herron, 1975).

Appendix 1 shows many examples of the diversity in cognitive abilities of chemistry students functioning at the concrete operations level compared to chemistry students functioning at the formal operations level. Since research shows that approximately half of beginning chemistry students are

functioning at the concrete operations stage and the balance are functioning at the formal operations stage, the concern may arise regarding how to best deal with this range of cognitive development of students enrolled in one course. Although possible solutions might include deferring teaching chemistry to all students until they reach a point (if one exists) at which all are functioning at the formal operations stage of cognitive development, or to exclude those students functioning at the concrete stage from taking chemistry, such drastic solutions are apparently unnecessary. Beistel (1975), Herron (1975), and Smith (1978) all instead suggest:

> 1) Adjusting the instructional techniques used in the course to match the cognitive development of those students functioning at the concrete operations stage; and
>
> 2) Presenting materials in a manner in which these same students are encouraged to develop cognitively towards the goal of functioning consistantly at the formal operations stage of cognitive development.

Herron (1975) elaborates on these suggestions with a reflection of how chemistry courses are sometimes mismanaged by their instructors. He states that not only have many chemistry instructors missed the mark on matching the instruction to the students' cognitive stage; others do not

promote further cognitive development of their students. Since many students (because of their stage of cognitive development) have to rely on memorizing the material, some instructors teach entirely to the concrete stage of development. Since they teach entirely to this stage, their students are never encouraged to function at a higher stage of cognitive development. The course then continues to be taught entirely at the concrete stage, thus creating a nonproductive carrousel. The better alternative is to meet the stage of cognitive development that each student is presently functioning at while at the same time promoting further cognitive development in each student (Beistel, 1975; Herron, 1975; Smith, 1978).

How to Determine A Student's Level of Cognitive Development

Operating under the assumptions that:

1) Beginning chemistry students are indeed found to be functioning at either the concrete operations level of cognitive development or at the formal operations level of cognitive development; and
2) There is a considerable difference in what a chemistry student functioning at the concrete operations level of cognitive development can comprehend compared to what a chemistry student

functioning at the formal operations level of cognitive development can comprehend,

a chemistry instructor might be interested in locating tests that claim to identify the students' stages of cognitive development so that he/she may better plan classes for the students. One such test is the Arlin Test of Formal Reasoning (Arlin, 1984). Since students may be thought of as functioning cognitively at a given point on a spectrum of cognitive development, this test expands on Piaget's stages of cognitive development and therefore more accurately delineates students' developmental abilities within the spectrum.

These stages, along with the number of correct answers given on the Arlin Test of Formal Reasoning, are:

| Number Correct (32 maximum) | Description of Stage |
|---|---|
| 0-7 | 1) Concrete. Students show no evidence of abstract reasoning and may have difficulty with reasoning skills that are specific to certain problems; |
| 8-14 | 2) High Concrete. Students provide some evidence of a systematic approach to problems. However, they show no evidence of |

being able to form general rules or abstractions from problems. In other words, there is some ability to classify and organize information but no evidence the ability to make inferences;

15-17 3) Transitional. Students at this stage provide some evidence of a systematic approach to problem solving as well as evidence of using some abstractions and inferences, even though they tend to be used inconsistantly;

18-24 4) Low Formal. Students provide evidence of being capable of abstractions and of making inferences but need to be provided with opportunities to develop these skills further

25-32 5) High Formal. Students provide very consistant evidence of using abstractions and making inferences in their thinking skills (Arlin, 1984).

The Arlin Test of Formal Reasoning (ATFR) consists of 32 multiple-choice questions. Designed to be administered to any student in grades six through twelve in a setting in which the student may use as much time as needed to complete it, the test instructions state that 45 minutes are usually sufficient. Based on the students' number of correct answers, the ATFR is designed to provide instructors with an

indication of students' thinking skills and whether they can use different types of concepts in their thinking. Arlin adds that the test might also be suitably used in conjunction with other instruments for screening students for programs for the gifted and talented and for early admission to special science and math classes (Arlin, 1984).

The test kit consists of a classroom set of test booklets, answer blanks, answer key, and test manual. The manual includes the history of the test's development, the descriptions of the stages of cognitive development, and tables describing mean scores of "typical" United States students functioning at each cognitive stage of development at each grade level.

Another test of cognitive development is the Inventory of Piaget's Developmental Tasks (IPDT), developed by the Center for research in Thinking and Language , Department of Psychology , Catholic University, Washington, D.C. 20017. This is an untimed, 72 item multiple-choice question test very similar to the AFTR. However, the test results may only be compared to mean scores of "typical" students at each grade level. The IPDT provides no means of translating the score into a stage of cognitive development.

Adapting the Chemistry Instruction to Meet the Needs of Students Who Function at the Concrete Operations Stage

Once a chemistry instructor has acknowledged that:

1) Many beginning chemistry students are functioning at the concrete operations stage of cognitive development; and that

2) Major goals are to:

A) Ensure that such students comprehend what is taught; and to

B) Promote further cognitive development of such students (Beistel, 1975; Herron, 1975; Smith, 1978),

a multitude of helpful suggestions from the literature may be utilized to help such students. Many will now be described.

Chemistry instructors and chemistry textbook authors should be required to read the annual Proceedings of the Jean Piaget Society. Being cognizant of Piaget's studies and their correlations to chemistry students might result in chemistry courses that are more comprehensible to students and thus might reduce the the numbers of college freshmen on probation at public institutions (Beistel, 1975).

It is important for chemistry instructors to realize that students functioning at the concrete operations level may be

able to give a rote memory definition of grams, moles, liters, and moles per liter, for instance, and yet may be unable to understand the concepts behind the terms (Cardulla, 1987). To help such students comprehend the subject matter, chemistry instructors should approach a topic in many ways (Herron, 1975). Piagetian theory supports this idea (Beistel, 1975). Besides presenting the content as a conventional lecture and problem solving format, examples include providing extensive experiences with concrete props that model abstract concepts. Physical models and films are good examples of such props (Herron, 1975). Furthermore, such students also benefit by being able to hold objects, measure grams, and draw pictures representing the concepts (Cardulla, 1987). Herron (1975) adds that lab work should include concrete experiences (touch, smell, see, manipulate) coupled with questions that encourage the students to think about what they are doing.

Instructors should remember to show all students the "big picture," in other words, of how all of the individual steps (of a problem-solving sequence or of a series of facts about a family of elements on the periodic chart, for instance) fit together in the overall scheme of the unit (Frank, Baker, and Herron, 1987).

To stimulate cognitive development of all students, instructors should first introduce new topics in concrete

terms. Cardulla (1987), for example, has found one helpful way of relating grams and moles in concrete terms. He uses the following discussion to make the connection: There are 3,000 students in a high school. There are 30 students per room. How many rooms are there in the high school? (Answer: 100) Once students understand that students in the school represent grams and students per room represent molar mass, they can solve for rooms, which represent moles. The point is, whenever possible instructors should make concrete examples of abstract concepts.

Once the students are familiar with a topic that has been introduced in concrete terms, Karplus (cited in Belstel, 1975) suggests that class discussions should be accompanied by the instructor's occasional false statements for students to correct. The instructor will not appear foolish if the students expect an occasional deception. In fact, such activities not only promote cognitive development but often provide those students already functioning at the formal operations stage with an activity with which they thrive.

Overall, teachers must strive to keep any chemistry student in the role of the active problem solver while at the same time providing a strong likelihood for successful problem solving. Instructors who stay interested in and enthused about problem solving promote active problem solving in their students (Gilbert, 1980). Instructors must realize

that student difficulties may be accentuated by the fact that the numbers they give the students while solving problems often involve decimals and exponents and therefore are rarely "nice and even." Therefore, providing problems that contain "simple" numbers (nonexponential and nondecimal) will build problem solving confidence in those students functioning at the concrete operations stage, especially as new concepts are first introduced (Cardulla, 1987).

A major difficulty for students functioning at the concrete operations level regarding problem solving is that the problem (to the student) is usually just an exercise to the teacher. A lecture format may not truly uncover the problem solving steps, but instead may merely supply the students with a set of steps to memorize without needing to comprehend the concepts involved. Therefore, the teacher will reach more students if he/she initially solves problems with the students rather than for them (Frank, et al., 1987; Mettes, et al., 1981). As the students gain confidence, they should be better able to solve problems on their own. Youmans (1971) suggests a seven-step process regarding problem solving that students and the instructor may initially practice doing concurrently in the classroom:

1) Write down what is asked for in the problem.
2) Locate information in the problem that will assist in solving it.
3) Consider any other known facts that will help solve the problem.
4) Seek out any other available resources, such as texts, friends, and charts.
5) Try out the possible solutions.
6) Check the answer to see if it seems reasonable.
7) Consider if this problem can be related to similar problems.

Bodner (1987) offers a set of similar suggestions for teaching problem solving. The instructor may solve problems with the students while following these steps:

1) Read, and then reread the problem.
2) Write down the key information, and then reread the problem another time.
3) Draw a diagram of the situation if applicable.
4) After locating a potentially useful formula from notes or from texts, make a calculation. Try another calculation if neccessary, and notice if this seems to lead toward what is asked for in the problem.
5) Locate more formulas and perform more calculations if necessary to obtain a final answer.

Bodner (1987) reminds us that explaining in this fashion is a much better approach than simply reciting a standardized set of formulas or routine procedures for solving the problem. Ryan (1987) relates problem solving to crossing a brook by throwing out stepping stones: students should write down all the substeps they recognize, then put them in logical order. Litle by little, the problem should be successfully solved.

Gilbert (1980) notes that students who solve problems successfully usually identify the **givens** in the problems and often reread the problem and write down the information. These students also use reasoning to attack the more difficult problems rather than relying on rote memory. The teacher can teach specifically to these skills as s/he works through sample problems with the class, thus saving class time (Gabel, 1987; Gilbert, 1980).

A negative aspect of teaching problem solving is that it uses up valuable class time, and many instructors opt for continuing with their daily lesson material instead. Consequently, chemistry students tend to learn problem solving haphazardly, if at all. Again, the teacher needs to outline and initially work through the the basic problem solving steps <u>with</u> students whenever such steps exist (Youmans, 1971). If this is done <u>as</u> new concepts are

introduced, the extra time involved in teaching the problem solving should be minimized.

Instructors should encourage those students having problem solving difficulties to give an easily remembered name (such as "Total/ Part") to the type of problem before they try to solve it, rather than only referring to the problem by its accepted title (such as "ideal gas law") (Ryan, 1987). In addition, seeing a worksheet of twenty problems can be overwhelming for such students; their being able to group problems into perhaps only four different types makes such work more manageable (Middlekamp, 1987), and improves the likelihood that the students will atttempt to complete the worksheet.

It may help students functioning at the concrete operations stage to know that they are not always expected to know the whole solution to problems as they begin work; this gives encouragement to the weaker students (Frank, et al., 1987). Likewise, it is worthwhile to show these students that not all problems contain all information neccessary to solve them. Teachers should explain how the students can sometimes draw on past knowledge for assistance (Gilbert, 1980).

Chemistry instructors should show all students how to estimate the answers to their problems to see if the answer

seems to be reasonable, especially with the increasingly popular use of calculators. After obtaining an answer, students must ask: Does it make sense? Is it in the correct units? Is the magnitude of the answer reasonable? (Gilbert, 1980).

The instructor's main function should be to facilitate learning, for it is the students who must do their own learning. Gilbert (1980) stresses helping the students develop confidence in themselves as problem solvers. Toward this end, students may work in small groups of two to three people (Mettes, Pilot, Roossink, and Kramers-Pals, 1981; Gilbert, 1980). This gives them the opportunity to verbalize their ideas along the way and gain the confidence needed to solve the problem (Gilbert, 1980). The teacher should visit groups and check their work, making suggestions as necessary while being careful not to show them how to solve the problem, but instead to direct them (Mettes, et al, 1981).

Finally, Mettes, et al. (1981) suggest giving "test conditions" problems to students towards the completion of the unit, in which the students work on problem solving independently and with a time limit, just as they would need to do when completing the actual unit test. This gives the teacher and students a clear indication of those students

that need the most guidance to promote mastery before taking the actual test.

Conclusion

Recent research has shown that approximately 50 % of students enrolled in general chemistry courses are functioning at the concrete operational stage of cognitive development. Other research points out that chemistry is inherently formal, thus putting such students at a disadvantage. Solutions offered to chemistry instructors include:

1) identifying those students functioning at the concrete operational level via diagnostic tests such as the AFTR; and
2) adapting instruction to meet their needs while concurrently promoting continued cognitive growth.

If done successfully, the instructor and students may feel the time and effort spent in the general chemistry course was a very worthwhile experience. The next chapter will illustrate the application of many of the suggestions described in this chapter in a general chemistry setting in a rural Wisconsin high school.

# CHAPTER 3

# ASSESSMENT OF HIGH SCHOOL STUDENTS' STAGES OF COGNITIVE DEVELOPMENT

## Introduction

The previous chapter concluded that, while general chemistry is a course that is inherently formal, approximately 50% of the students enrolled in it tend to function at the concrete operational stage of congitive development. Presuming that the previous statement is true, suggestions were presented regarding ways to best teach general chemistry to students functioning at the concrete operational stage of cognitive development who are enrolled in the course.

This chapter will utilize the suggestions presented in chapter 2 for assessing students' stages of cognitive development using a population of 263 students enrolled in the four types of general chemistry courses taught at Mukwonago High School, a rural Wisconsin high school in Mukwonago, Wisconsin. (The school contains approximately 1600 students.) The chapter will include a description of the chemistry courses offered at the high school, and the apparent stages of cognitive development of the students enrolled in the chemistry courses, based on their performance on the Arlin Test of Formal Reasoning. The

relationships between these results and the chemistry courses students are enrolled in will also be discussed.

Course Descriptions

Chemistry is taught at Mukwonago High School in Mukwonago, Wisconsin via four chemistry courses. All are year-long courses complete with extensive problem solving and laboratory exposure. I am one of three teachers who teach the courses. Cooperation and joint planning among the three of us is very extensive so that all students enrolled in each course are presented with the same textbooks, explanation sheets, worksheets, laboratory experiences, and tests, even though they may have any of three teachers teaching them. In this way, colleges, as well as our own upper-level chemistry course instructors, are assured of receiving students who have all had similar exposure to general chemistry at Mukwonago High School regardless of the individual instructor in the course. Because of this joint effort and resultant uniformity in instruction, I feel that the entire chemistry student body lends itself well to a group analysis of the sort that follows, as the inconsistancies due to individual instructors are minimized. A general description of the courses and their main goals follow:

1. CHEMISTRY I: This course is the typical high school general chemistry course that many students enroll in in order to receive their first formal extensive exposure to chemistry. It is recommended to be taken by all college-bound students. Chemistry I has as the bulk of its enrollment eleventh graders, although some tenth graders and some twelfth graders are also enrolled.

2. "AT" CHEMISTRY I: This course is similar to Chemistry I, except that it is faster-paced and includes supplemental enrichment units and enrichment laboratory activities along with a greater emphasis on independent work. Taught only to tenth graders deemed to be "academically talented" based on standardized CTBS test scores, math grades, and teacher recommendations, enrollment in this course is voluntary. It is the first formal extensive exposure to chemistry for these students.

After a student has successfully completed either of the two courses listed above, they may choose to enroll in one or the other of the two following courses during their remaining years in high school:

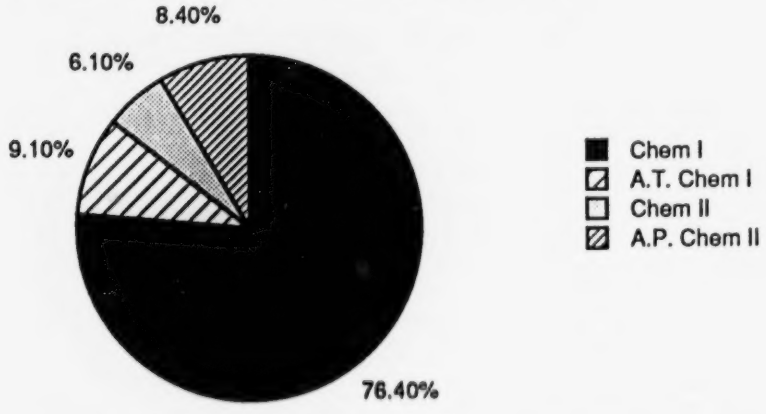
3. CHEMISTRY II: This course is equivalent to freshman level general chemistry presented in college. It covers concepts presented in the previous chemistry courses in

greater detail and stresses increased independent work and more extensive laboratory experiences when compared to the previous courses. It is suggested that students who enroll in this course be those who have earned at least a "B" average in both the previous chemistry course and in their math courses. It is composed of eleventh and twelfth graders.

4. "AP" CHEMISTRY II: Very similar to the above course, this course is tailored to those students wishing to take the Advanced Placement Chemistry Exam upon entering college as a means of bypassing general chemistry coursework in exchange for advance placement credit. This course involves extensive laboratory experiences and independent work. Classtime is also spent reviewing the material on and the format used by the Advanced Placement Exam. It is suggested that students who enroll in this course be those who have earned "A" grades in the previous chemistry course and their recent math courses. It is composed of eleventh and twelfth graders.

The relative percentages of chemistry students enrolled in each of these chemistry courses in 1988-1989 are indicated in Figure 1:

**Figure 1: Total Chemistry Enrollment by Course**




number of students = 263

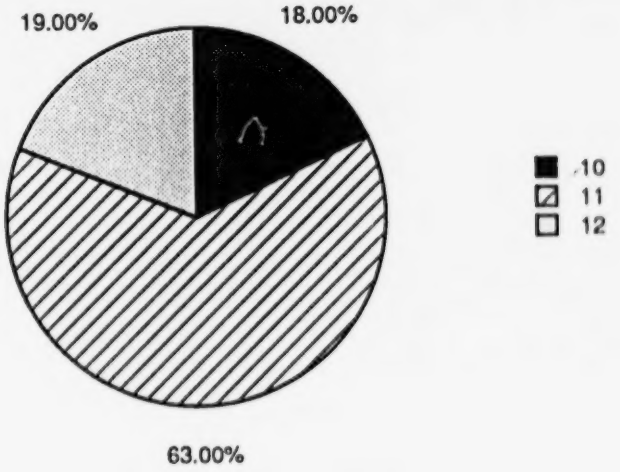
The total chemistry population is composed of mostly eleventh grade students, with approximately equal percentages of tenth and twelfth graders making up the balance, as shown in Figure 2.

Test of Cognitive Development

In an effort to determine the apparent stages of cognitive development of students enrolled in chemistry courses at Mukwonago High School, I administered the Arlin Test of Formal Reasoning (ATFR) to every chemistry student attending every chemistry course at Mukwonago High School on a randomly determined day. A total of 263 students took the

test in a conventional classroom setting. The students were informed, as the test suggests, that the purpose of the test was to determine the types of thinking styles they use when solving problems. In addition, they were told that the results would be used to better plan the course to meet their needs.

**Figure 2: Total Chemistry Enrollment by Grade Level**




number of students = 263

I anticipated that the test would provide me with a breakdown of the stages of cognitive development displayed by students, as well as various relationships between groups of students within the chemistry population as a whole. The findings of the ATFR will be elaborated on following a description of the test itself.

## The Arlin Test of Formal Reasoning

As mentioned in the previous chapter, the ATFR is a 32-question, untimed, multiple choice test. It can be easily presented in a classroom setting as a means of determining the approximate stages of cognitive development of those students taking the test. The test booklet states that it typically takes students 45 minutes to complete the test.

Based on the number of items answered correctly, the ATFR classifies the student's stage of cognitive development as high formal, low formal, transitional, high concrete, or low concrete. The number of items answered correctly and a description of each stage follows:

| SCORE | DESCRIPTION OF STAGE |
|---|---|
| 0-7 | 1) Concrete. Students show no evidence of abstract reasoning and may have difficulty with reasoning skills that are specific to certain problems; |
| 8-14 | 2) High Concrete. Students provide some evidence of a systematic approach to problems. However, they show no evidence of being able to form general rules or abstractions from problems. In other words, there is some ability to classify and organize information but no evidence of the ability to make inferences; |
| 15-17 | 3) Transitional. Students at this stage provide some evidence of a systematic approach to problem solving as well as evidence of using some abstractions and inferences, even though they tend to be used inconsistantly; |
| 18-24 | 4) Low Formal. Students provide evidence of being capable of abstractions and of making |

inferences but need to be provided with opportunities to develop these skills further;

25-32 5) High Formal. Such students provide very consistant evidence of using abstractions and making inferences in their thinking skills (Adapted from Arlin, 1984).

In the data analyses that follow, these five categories will often be referred to as "Arlin categories," even though they are related to Piaget's Stages of Cognitive Development.

ATFR Results

I was able to learn a great deal about the chemistry students through the administration of this single test. By filling out the answer sheets that were provided with the ATFR, students supplied me with the following information when they took the test that day:

-name
-age
-sex
-grade level in school
-chemistry course enrolled in
-ATFR answers

The test booklet suggests that the ATFR be used as a means of categorization of student's stages of cognitive development, as well as a means of screening students for programs for the gifted and talented and for early admission to special science and math classes. It must be kept in mind, however, that the use of a single test such as the

ATFR is not recommended as the sole factor upon which to categorize individual students (Arlin, 1984). In addition, while the test has been favorably analyzed for validity and reliability (Arlin, 1984), some students taking the test may have had a bad day, and test results for such students may not result in accurate measurements of their stage of cognitive development.

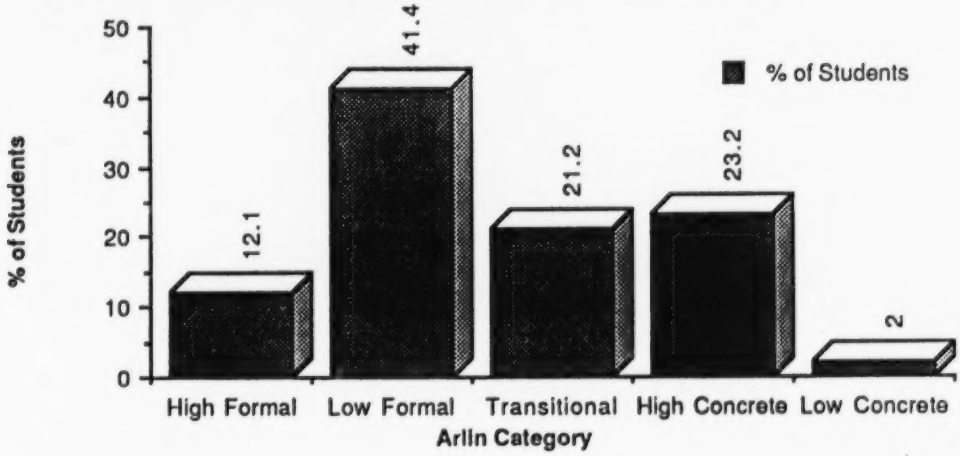
Nevertheless, it was my hope, as I began my study, that the large sampling of 263 students who took the ATFR test on that day would provide me with enough data to see general trends and make extrapolations to the teaching of general chemistry, at least at Mukwonago High School. The following is an analysis of the data obtained, along with some brief comments regarding the implications of the data to the teaching of a high school chemistry course.

I analyzed the data obtained from the ATFR in many ways in an effort to see the extent to which the stages of cognitive development of our chemistry students match that of students in the chemistry courses cited in the review of the literature. In addition, I analyzed the data to examine how well the stages of cognitive development match the type of chemistry course that students are enrolled in. These comparisons will now be discussed in further detail.

DESCRIPTION OF TOTAL CHEMISTRY ENROLLMENT

Using the ATFR data, I was able to create the following illustration of the stages of cognitive abilities of the entire chemistry enrollment (all four courses) as a single group (see Figure 3):

**Figure 3: Total Chemistry Enrollment by Arlin Category**




The review of the literature stated that typically 50 percent of chemistry students function at the concrete operations stage, 25 percent function at the formal operations stage, and (I presume) the remaining 25 percent function inconsistantly at either stage and therefore might be considered at a transition point between the two stages (Herron, 1975). Presuming the ATFR results to be accurate indicators of cognitive abilities, my data show that

approximately 25 percent (23.2% + 2%) function at the concrete operations stage, 54 percent (41.4% + 12.1%) function at the formal operations stage, and 21 percent function at the transitional stage.

While it is heartening to realize that a larger than typical cluster of students functions at the formal operations stage, 25 percent of the population functions at the concrete operations stage. In addition, 21 percent function at the transitional stage, meaning that they are likely to revert to concrete thinking when faced with new intellectual challenges (Herron, 1975). Based on the percentages of students functioning at the transitional and concrete operations stages, I was motivated to compare the instructional techniques I use to those recommended by the literature in order to determine if there was more that I could do to help students functioning at the transitional and concrete stages of cognitive development to better understand the chemistry concepts presented. That analysis will be elaborated upon in Chapter 4. First, I will describe additional ways I found to use the ATFR results in order to get a better "picture" of the students enrolled in the chemistry courses at Mukwonago High School.

CORRELATION OF ATFR TO CHEMISTRY TEST SCORES

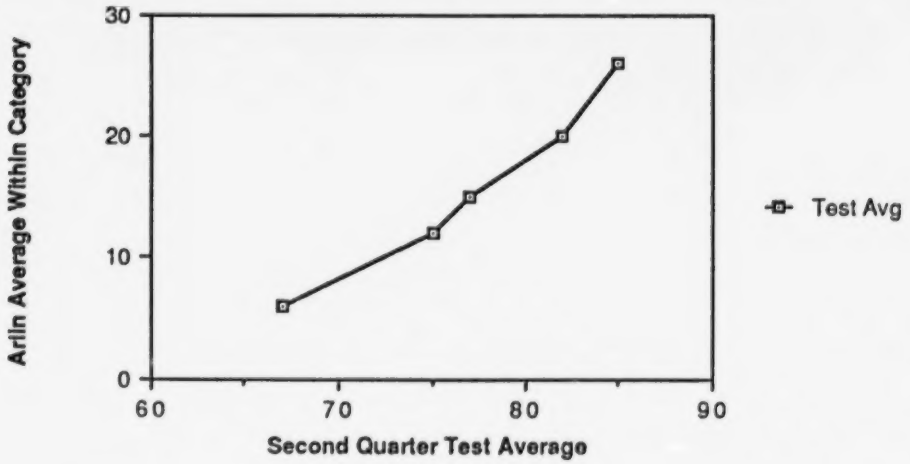
Before analyzing the chemistry population in smaller subgroups, I decided to examine whether the ATFR results showed any correlation to the actual test grades the students were earning in their chemistry courses. I gathered data regarding each student's second quarter test average percentage. The grades earned from doing our lab work were not used for this comparison, as they generally tend to inflate the student's overall course grade; our labs are more often a practice in laboratory technique and following directions than a test of cognitive ability. The classroom tests are, therefore, regarded by the chemistry instructors here as a more accurate measurement of cognitive ability.

The second quarter test averages were chosen because they not only coincided with the time that the ATFR data were collected, but they reflect more true chemistry calculations than first quarter test averages might, since first quarter chemistry coursework involves a fair amount of general review of math and science concepts, without delving fully into chemistry concepts.

I calculated the chemistry students' ATFR average score within each of Arlin's five stages of cognitive development. I then calculated the chemistry students' chemistry test average score for those students comprising each of Arlin's

five stages of cognitive development (see Figure 4). Although the averaging done within each category loses details, I hoped that I would still be able to see general trends in the correlation.

**Figure 4: Arlin Test Scores/ 2nd Qtr. Test Averages**

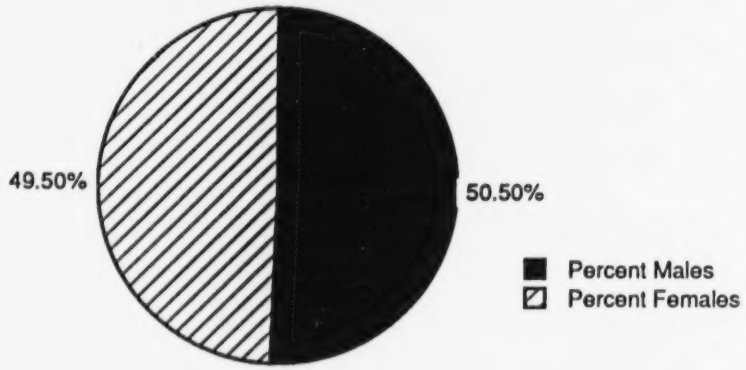



From this graph I can see that a positive correlation exists between students' ATFR score and their second quarter chemistry test average percentage: those students who tend to score well on the ATFR also tend to be the ones who score well on the chemistry tests. These results gave me even greater confidence in the usefulness of the ATFR as a means of determining the stages of cognitive ability of our chemistry student population.

ATFR ANALYSIS BY SEX

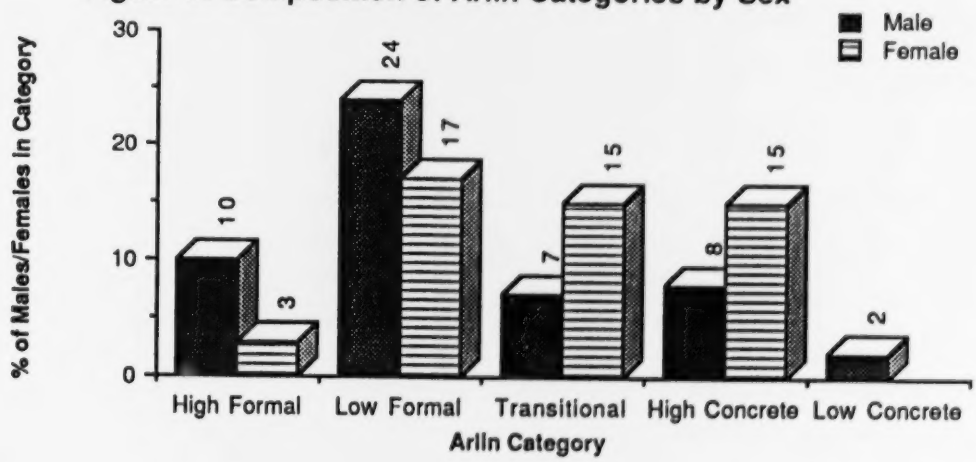
Out of simple curiousity, I next decided to determine if there were any relationships apparent regarding the sex of students and their stages of cognitive development as determined by the ATFR results. First of all, the total chemistry student population turned out to be very evenly divided between males and females (see Figure 5).

**Figure 5: Total Chemistry Enrollment by Sex**




However, when I examined the Arlin Categories that male and female chemistry students were able to be placed into based on their ATFR score, Figure 6 resulted.

**Figure 6: Composition of Arlin Categories by Sex**

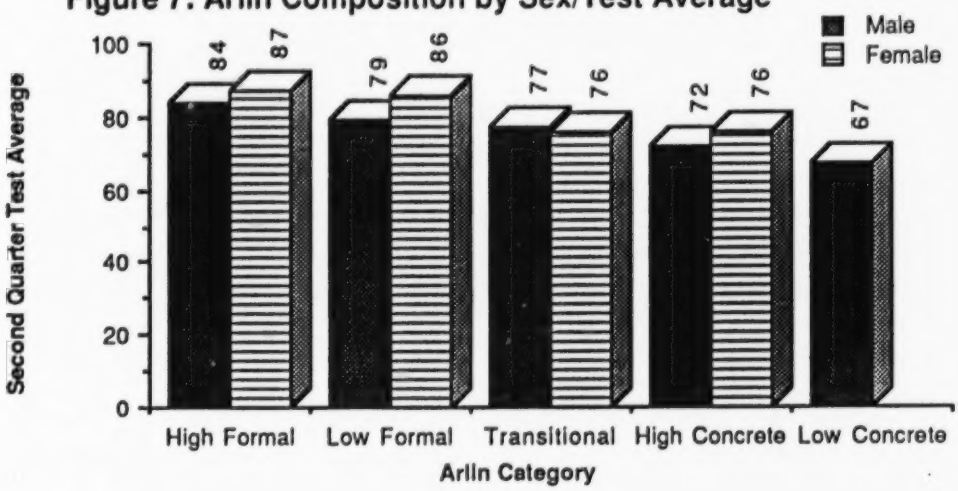



I found it fascinating to realize that this set of data (Figure 6) showed me that, even though the population was evenly divided into males and females, many more males than females fell into the formal categories. In addition, many more females than males fell into the transitional and high concrete categories. Interestingly enough, those students who scored in the low concrete category were all males, however.

I was then curious to find out if any trends could be visualized if I compared the chemistry test average score mentioned above to the Arlin category the males and females fit into. In nearly every Arlin category that they were grouped into, the females averaged higher on their chemistry test scores than the males did (see Figure 7). In light of

the fact that females were greatly outnumbered by males in the formal operations Arlin categories, I find this especially thought-provoking: Does this mean that those few females functioning at the formal operations stage have better figured out how to play the academic game of "schoolmanship," and thus earn higher academic grades even though they are cognitively outnumbered by males?

**Figure 7: Arlin Composition by Sex/Test Average**




ATFR ANALYSIS BY COURSE

Figures 8, 9, 10, and 11 show the percentages of students categorized into each of the five Arlin stages of cognitive development within each chemistry course.

**Figure 8: Chem I Enrollment by Arlin Category**

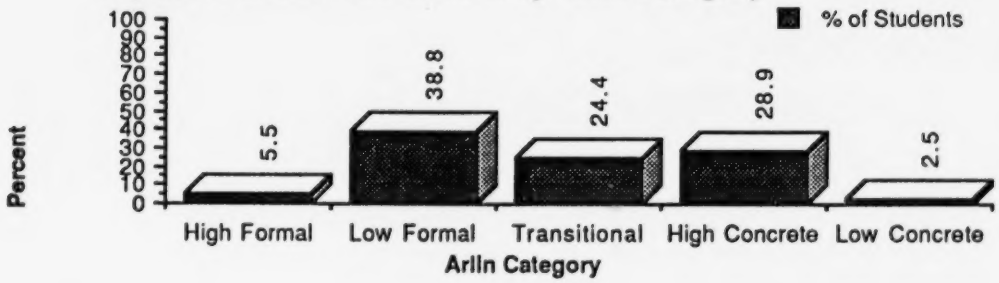



**Figure 9: AT Chem I Enrollment by Arlin Category**

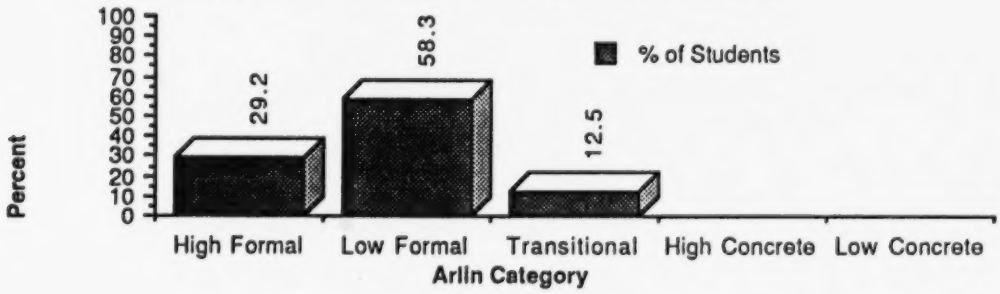



**Figure 10: Chem II Enrollment by Arlin Category**

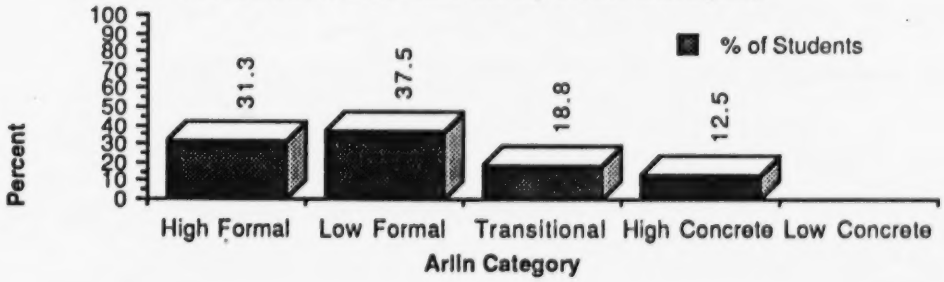
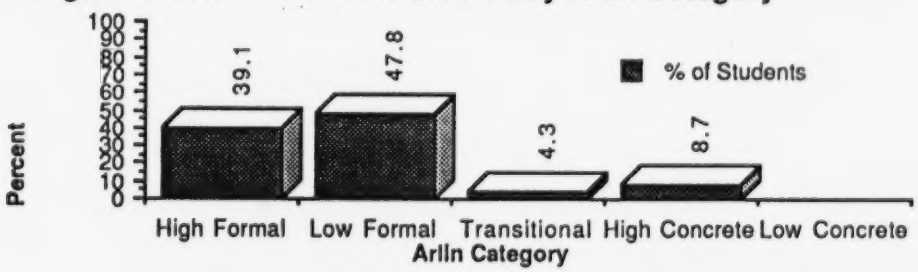



**Figure 11: AP Chem II Enrollment by Arlin Category**



These graphs are ranked on the page according to increasing general cognitive demands that each course places on the students enrolled in it, with Chem I being the least demanding and AP Chem II being the most demanding. By knowing this and examining the ATFR results within each course, it appears that the most demanding courses include large percentages of students functioning at the formal operations stages, and vice versa. In other words, many students seem to be cognitively well matched to the chemistry course they are enrolled in. It is worth noting that even the two second year chemistry courses contain students still functioning at the concrete and transitional stages, however, and the AT Chemistry I course does not.

While examining the results of these graphs, I also noticed that the special first-year chemistry course, AT Chem I, showed approximately 87 percent (29% + 58%) of its students functioning at the formal operations stages, as compared to the top level second year chemistry course, AP Chem II, with 88 percent (39% + 49%) (compare Figures 9 and 11). I find this especially noteworthy because the students enrolled in the former course are all tenth graders, as compared to eleventh and twelfth graders enrolled in the latter. Perhaps this means that the students functioning at the formal operations stage of cognitive development when enrolled in AP Chem II are for the most part from the population of

students who tend to enroll in AT Chem I. Analyzing the chemistry student population during the course of several years might determine if this is so. Further analysis of Figures 9 and 11 shows an increase in students functioning at the high formal level of cognitive development and a decrease in the students functioning at the low formal level of cognitive development. This is a logical progression, based on how Figure 9 represents tenth grade students, and Figure 11 represents eleventh and twelfth grade students.

If the statements made in the preceding paragraph are true, perhaps the students who enroll in Chem II are mostly students who had enrolled in the Chem I course previously. If so, Figures 8 and 10 show their stages of cognitive development to progress to higher stages during this time. Again, analyzing the chemistry student population during the course of several years might determine if this is so. After drawing these conclusions, I decided to compare the data another way.

## ATFR ANALYSIS BY GRADE LEVEL

By breaking down the ATFR results into grade levels of students enrolled in our chemistry courses, Figures 12 - 14 resulted. I can see from these figures that the general distribution of students within the Arlin categories for

**Figure 12: Grade 10 Enrollment by Arlin Category**

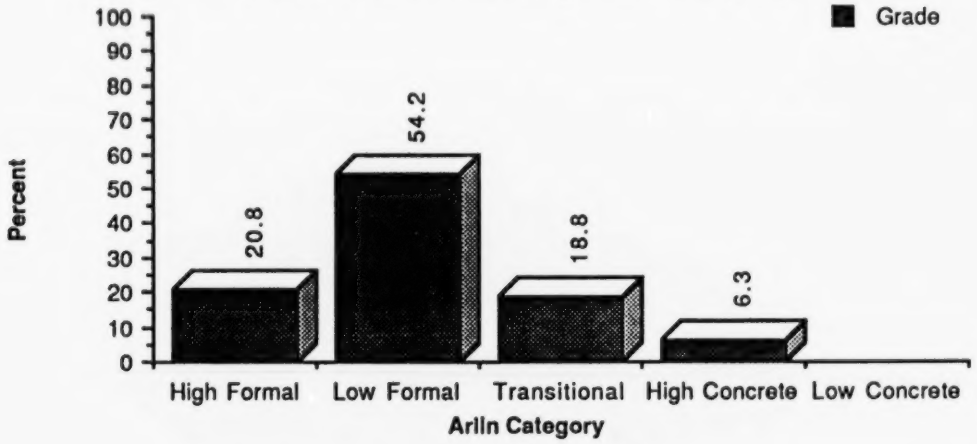



**Figure 13: Grade 11 Enrollment by Arlin Category**

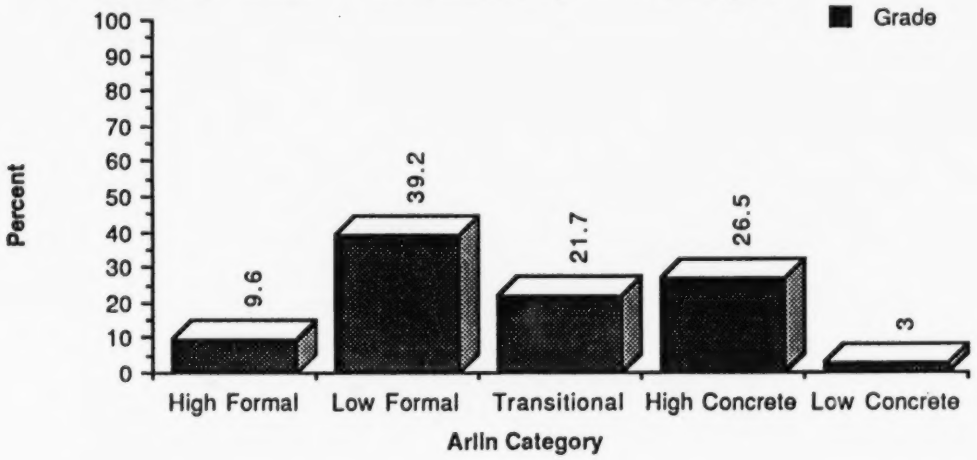
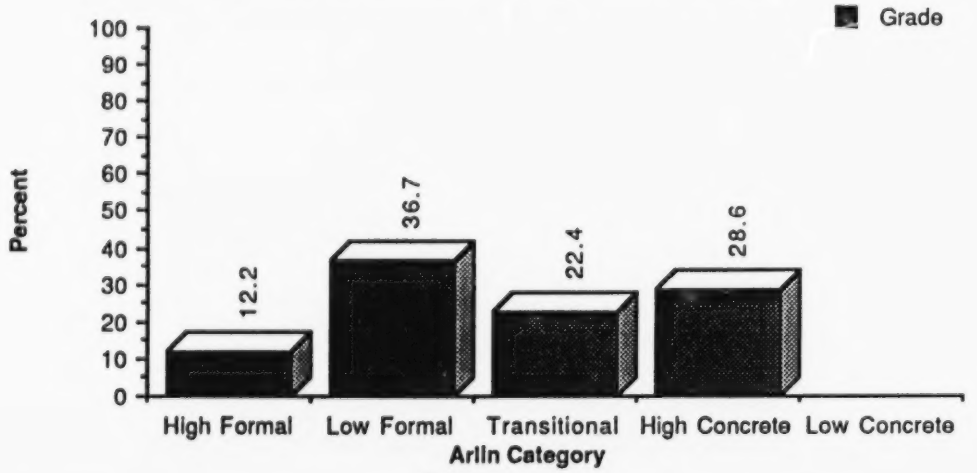



**Figure 14: Grade 12 Enrollment by Arlin Category**



each grade level is roughly similar. However, while the tenth grade students represent the largest percentage of students to be functioning at the high formal stage of cognitive development, it must be kept in mind that they are mostly students officially recognized as being academically talented, while the eleventh and twelvth grades represent a more academically mixed group of students. Nevertheless, from these graphs, as well as from the previous set, I can postulate that the stage of cognitive development of an individual is not directly and simply associated with the grade level (and therefore the age) of the student; perhaps one's cognitive development is more directly linked to the environment (home and school experiences, for instance) and/or even to genetic background.

## Conclusion

I found it fascinating to analyze the ATFR results to obtain a better "picture" of our students' stages of cognitive development. As mentioned earlier in this chapter, the total chemistry enrollment's ATFR scores showed 54% of students functioning at the formal operations stage, and therefore likely to be able to comprehend the many abstract concepts presented in the general chemistry curriculum without undue difficulty. However, just as the literature review predicted, the ATFR results showed that many students

function at the transitional and concrete stages (21% and 25% respectively), and therefore may have difficulty understanding the chemistry concepts presented, which tend to be inherently formal by nature. The following chapter will address adapting the chemistry instruction to meet the needs of those students functioning at the transitional and concrete stages of cognitive development, and the students' and instructor's responses to those adaptations.

# CHAPTER 4:
# ADAPTATION OF CHEMISTRY INSTRUCTION

The ATFR results analyzed in the previous chapter showed large percentages of our general chemistry students to be functioning at the transitional and concrete stages of cognitive development. This chapter will describe an effort made to determine if the presentation of instructional content in the general chemistry courses (largely eleventh grade students) that the majority of the students are enrolled in meets the needs of such students. Student response to the course presentation will be noted. The instructor's reflections on the applications of the new suggestions used in the course will be included throughout the chapter.

## Analysis and Modification of Chemistry Instruction

The review of the literature in Chapter 2 included numerous suggestions of ways for chemistry instructors to adapt their instruction to enable chemistry students functioning at the transitional and concrete stages of cognitive development to comprehend the concepts presented. I condensed the suggestions presented in Chapter 2 into a three-page checklist (see Appendix 2) that enables a chemistry instructor to analyze a given unit or chapter. Blank areas

on the checklist indicate to the instructor those items needing to be developed (where applicable) to better meet the needs of those chemistry students functioning at the transitional and concrete stages of cognitive development.

Following the development of this checklist, I analyzed a unit presented in both Chemistry I and AT Chemistry I, the courses I teach. The unit, Liquids and Solids, can conceivably be presented in a very formal nature by some chemistry instructors. In this unit students need to perform numerous calculations related to Molarity (concentration of solutions) and stoichiometry (relationships of the amounts of reactants and products in a given chemical reaction). In its most complex form, this unit includes a problem set in which two solutions are mixed together resulting in a precipitate (solid) being formed. The students are asked to calculate, on paper, the concentrations of the reactants and products in the solutions (1) before the solutions are mixed, (2) at the moment they are mixed, and (3) after the precipitate forms and settles out to the bottom of the container containing the solutions.

I have long had a feeling that the vast majority of the students enrolled in my courses have felt that their time spent in class is worthwhile, and even though they may struggle trying to understand the concepts at times, they feel that if they put in the effort I will put in the

effort, and in the end they usually understand the concepts. Perhaps this means that the instruction presented in the course already closely approximates many students' stages of cognitive development. If true, perhaps this close match instills in my students the perseverance to tackle mastering new concepts, knowing that they will likely be able to comprehend them satisfactorily before the unit test date.

As I went down my checklist while analyzing the unit, I was pleased to note that indeed most of the way the Chemistry I and AT Chemistry I curricula are presented to the students already matches the suggestions presented on the list. By thinking about other chemistry units, I found this to be true in them as well. I could determine only two major weaknesses that needed correcting:

> a need to diagram (flowchart) the "big picture" in order to help the students visualize the overall concepts rather than being bogged down in just performing individual calculations; and
>
> a need to supplement the concepts presented using audiovisual media.(Our chemistry department currently has none.)

I developed an explanation sheet (see Appendix 3) for this unit that presented the "big picture" to the students (using diagrams and summarizing paragraphs), without using any potentially intimidating example problems. In addition, I supplied the students with a separate explanation sheet (see Appendix 4) that summarized the overall concepts and included example problems along the way. I hoped that the

students would therefore be encouraged to learn the underlying concepts from the first explanation sheet and then be willing to work out problems related to the concepts by following the example on the second explanation sheet.

Although most of the students in the AT Chemistry I course were found to be functioning at the formal stage of cognitive development (see Figure 9), and therefore might not need the explanation sheets, 13% were found to be functioning at the transitional stage of cognitive development and, I felt, would probably benefit from them. I gave the sheets to all students in my Chemistry I and AT Chemistry I courses -- the courses in which these concepts are first presented.

I began by discussing the underlying concepts contained in this chemistry unit while my students followed along on the first explanation sheet (Appendix 3). Because this sheet gave them an understanding of the main concepts in the unit, I next pointed out how the second explanation sheet (Appendix 4) took these concepts and applied them to a laboratory example complete with chemical formulas and specified amounts. Finally, I concluded by assigning worksheets that helped them work through this units' concepts in the same manner that the explanation sheets did. Appendix 5 is an example of one such worksheet. The

explanation sheets received unsolicited favorable verbal and written responses from the students.

In addition to the explanation sheets, I attempted to locate supplementary audiovisual materials. I wanted to obtain materials that would be easy to use as short (15 minute) presentations of a single topic, easy to store, interesting for the students to watch and listen to, and current with respect to recent advances in technology. Because of time and budgetary restrictions, I was not able to purchase or preview any materials soon enough to be included in this study. However, I did learn of a laserdisc just published by the Journal of Chemical Education: Software that may be an example of what I had been searching for. Because of their format, laserdiscs can be used to quickly reinforce many specific ideas without the need for tedious search and rewind actions associated with many other forms of audiovisual materials: selected sequences can be located for playback usually within 2 seconds. Laserdiscs are very durable and, because they are nearly as thin as a phonograph record, storage space is no problem. One disc can hold tens of thousands of images (stills and live action). I plan to purchase it for use with next year's students.

Student Evaluation of Modified Chemistry Instruction

On the same day that my students took the test on the Solids and Liquids modified chemistry unit, I asked them to anonymously complete a "Student Evaluation of Unit/Chapter" sheet (see Appendix 6) in an effort to determine how well they felt the unit had met their needs. The students were asked to pick up an evaluation sheet upon turning in their completed tests, fill it out, and return it to me. Of approximately 110 students in attendance that day, 82 evaluation sheets were filled out and returned.

I hoped that if the modified unit was well matched to the stage of cognitive development of many of the students in the course, they would feel that their time spent in the course was worthwhile. This could possibly contribute to the rather pleasant classroom climate and respectful teacher-student relationships that I felt were evident in the classes as I taught the modified unit. Based on the students' interactions with me, I surmised that the students would give largely favorable responses on their evaluation of the modified unit.

I chose to analyze three sets of responses from the students' evaluations, as I felt they gave me the most useful data relavant to this study. They are summarized below:

> Question 7 in the evaluation asked "How well do you feel you were able to understand the concepts presented in this unit? (1 being not very well, 5 being very well)."

Approximately 88% of my students felt that they understood the concepts quite well (responding with numbers 4 and 5), meaning that the unit had probably been presented at a level that matched the stage of cognitive development of most of the students.

> Question 8 in the evaluation asked "How well do you feel the teacher made an effort to explain the concepts of the unit to you in terms you could understand? (1 being not well, 5 being very well)."

Ninety-one percent of the students responded with a 5 and 4.8% with a 4. I interpret this to mean that the students felt that I had made a sincere effort to convey the concepts to them. If they still didn't understand, perhaps they did not work at it hard enough, they had not arranged for enough time outside of class in which to do homework, or they had other personal problems interfering with their concentrating on learning the concepts presented in this unit.

> Question 11 in the evaluation stated "Assuming that you had to be exposed to the concepts of this chapter/ unit no matter what, and that you made a decent effort to learn the concepts, do you feel that the hours you spent attending this class <u>were</u> worthwhile?
> _____ Please comment further, including suggestions for making this chapter/unit more worthwhile for students taking this course in the future."

Seven point three percent responded "no" and 92.7% responded "yes." The free-reponse area included several comments by students in some cases, and no responses in other cases.

The phrases that were listed by students, together with the frequencies in which they appeared, are summarized below. Phrases that I interpret to be contradicting previous phrases in the list are indented.

...Good Job/ Excellent...14
...This course is as worthwhile as any can get...3
...I understood this unit perfectly...6
...Don't change a thing...10
    ...The unit should be a little faster-paced...4
    ...Slow down the unit...2
    ...Do more labs...8
...This course is good for college preparation...7
...Doing this many reviews is good...4
    ...We spent too much time reviewing...5
...The problem solving gave me a chance to use my head...4
    ...I'll never use this stuff again...3
...Using class time to work out problems is a good idea...1
...Split the class into two groups to help the struggling students while the others work on the worksheets...1
...It's the student's job to work harder if they still have problems...12

I interpret the results of question 11 to be favorable responses, encouraging me to modify other units in the future. Further investigation could include determining if many of the negative phrases came from students functioning at the formal operations stages of cognitive development, thereby indicating that the modified unit was presented too

far below their stage of cognitive development for their satisfaction.

Summary

This study began with an awareness that learning general chemistry concepts, which are inherently formal, can be difficult for certain students, even though the students make a sincere effort to comprehend the concepts presented. An analysis of the literature revealed that a large percentage of these students may be functioning at the concrete and transitional stages of cognitive development and therefore may have difficulties understanding chemistry concepts when they are presented in a manner that requires formal thought. An analysis of a high school population of chemistry students using the ATFR confirmed this developmental situation.

Suggestions were presented for ways to identify the stages of cognitive development of students, as well as ways to modify the instructional methods used to teach the chemistry concepts so that struggling students might still be able to comprehend the concepts presented. These suggestions were applied to the general chemistry students enrolled in Chemistry I and AT Chemistry I, and the resulting data analyzed.

During this study I have obtained a clear picture of the stages of cognitive development of the students enrolled in chemistry courses at my high school. Presuming that the students presently enrolled are typical of the chemistry student body, I have been able to use my knowledge of their stages of cognitive development to analyze my chemistry instruction for its appropriateness to teaching the students who may enroll in it, with an emphasis on those students functioning at the concrete operational stage of cognitive development. Through the review of the literature, I have learned current appropriate methods to use when teaching chemistry to students functioning at the concrete stage of cognitive development. Based on the student responses on the evaluation of a modified chemistry unit, I feel that the chemistry instruction was successfully adapted to meet the needs of the majority of the students enrolled in the courses. I plan to apply what I have learned during this study to other chemistry units I teach in future years.

## Additional Thoughts From the Instructor

If the cognitive stage of instruction presented in a chemistry course is matched to the cognitive stage of development of most of the students in that course, I feel that most of the students will be able to comprehend the concepts presented. In addition, the self-esteem of the

students will likely be positive, resulting in increased motivation to complete assignments. Teacher-student respect may also increase as a result of the proper matchup of cognitive development in the student and in the instructional experiences.

Along with the cognitive development matchup just mentioned comes the possibility that a course could be too "watered down" for some students; i.e., those functioning at the formal operations stage may not be challenged enough if the higher-level thinking exercises are eliminated completely. In addition, if a course is taught in entirely concrete terms, those students functioning at the concrete operations stage may not be spurred on to further cognitive growth. I feel the compromise, then, is to:

1) present the course instruction at a level that most of its students can just barely comprehend, thereby urging continued cognitive growth while at the same time providing a reasonable situation for mastery of the concepts presented; and

2) separate off those students functioning at the higher stages of cognitive development (as has been done with the AT Chemistry students) so that they be taught the concepts using instruction at a stage of cognitive development more closely matching that at which they function.

Another topic related to this one might be an investigation into the best ways to present instruction to those students already functioning at the formal operations stage of cognitive development. Such students from this study would include much of the AT Chemistry I, Chemistry II, and AP Chemistry II enrollments.

Matching the stage of cognitive development of coursework to the stage of cognitive development of students, as well as promoting further cognitive development in those students, is particularly useful in encouraging a continued interest in science. As our technological advances occur at an ever-increasing rate, it is of prime importance that we stimulate students to deal confidently with the science-related issues in the world around them. Chemistry is one course in which we can do this.

# APPENDIX 1

Based on Herron's (1975) judgement of the mental activity required to perform tasks commonly presented in chemistry, the following chart was devised.The tasks have not been formally tested, however.

Students who are at the concrete operations level:

can do routine measurements or observations;
can't do measurements of density, heat of reaction, or other quantities not observed directly;

can make inferences which are direct extrapolations from observations;
can't make inferences twice removed from observations (If A=B and B=C, then A=C);

can comprehend that the hydrogen-to-oxygen ratio in water is constant IF presented from actual observations;
can't reason from the statement above that therefore compounds can be represented as particles made up of atoms combined in definite proportions;

can construct cooling curves and infer from their shapes whether the substance is pure or impure;
can't explain WHY the plateau occurs in a cooling curve of a pure substance during a phase change;

can predict the effects of temperature on kinetic energy when shown a physical model of gas behaviors;
can't, when given postulates of the kinetic theory, predict the temperatures and pressures under which real gases do not obey the ideal gas law;

can, following a definition of molarity, prepare 1000 ml of a 1 M solution;
can't, following the same definition, prepare 25 ml of a 2.5 M solution from a 3M stock solution;

can follow rules to find the empirical formula of a compound;
can't understand why, following those rules, one gets the empirical formula;

APPENDIX 1, PAGE 2

can realize that the atomic weight is the mass of a given number of molecules;
can't think of atomic weight as the ratio of the mass of one atom to that of another selected as a standard;

can use the factor-label method to solve problems if the labels indicated the operations to be performed;
can't use ratios and proportions to solve problems different from the ones memorized;

can balance equations, write formulas, calculate molar mass, etc. using set rules;
can't derive rules for the above from general principles;

can conceive of acids as any substances that turn litmus paper red;
can't conceive of acids as proton donors or electron pair acceptors;

can show that solutions contain ions if electrical conductivity occurs, measure current flowing in a solution, show that the mass of metal depoited on an electrode increase regularly with the current or with time;
can't predict changes in time needed to compensate for an observed change in current, use the amount of current and time to calculate the number of atoms deposited on an electrode;

can use rules concerning reaction rates to predict changes in rate which would result from a change in temperature and concentration;
can't explain the effect of the above to changes in terms of the collision theory;

can, when given a system at equilibrium, observe the effect of change in temperature, concentration, or pressure on some component and predict the state of the system when additional changes of the same type are made;
can't, given the same system at equilibrium, predict the effect on some other component of the system when the above changes are made. In addtion, when given an equilibrium expression, predict the concentration change on one component of the system when another component is changed;

APPENDIX 1, PAGE 3

can, when given the volume of base needed to neutralize one gram of acid, calculate the volume of base needed to neutralize any amount of acid;
can't, when given the concentration of base and the volume needed to neutralize a given volume of acid, calculate the concentration of the acid;

can begin constructing an activity series after placing various metals into a solution containing a metal ion;
can't construct an activity series from a series of labs like the above where some metals appear only in ion form while others appear as metals.

Adapted from Herron (1975)

Students at the formal operations level can accomplish the tasks listed above that the concrete operational student can not.

APPENDIX 2

UNIT/CHAPTER CONTENT ANALYSIS

COURSE NAME_____

DATE_____

UNIT/CHAPTER NUMBER AND TITLE _____

Check off those items that are <u>already</u> being done:

1_____allow students to work in groups of 2-3 whenever possible
2_____introduce problems in concrete format whenever possible
3_____break dowm process into several smaller steps
4_____present new problems by using "nice and even" numbers; then use "unusual" values after students understand the underlying concepts
5_____diagram (flowchart) the process to present the overall picture
6_____show how to classify problems: identify each style by an easily-remembered name
7_____approach subject in several ways (list them)

_____

8_____hands-on examples where applicable
9_____show students how to estimate answers as a check for accuracy
10____share tricks/ techniques you use to organize knowledge
11____work through new problems <u>with</u> the students as problems are introduced as though they are a true problem to you, rather than just an exercise
12____lead a student in narrating the solving of a problem in front of the class
13____present occasional false statements to the students and have them explain why they are false
14____show students how to estimate the magnatude of the answers to the problems as a check for accuracy
15____when studens ask for assistance, have <u>them</u> work through the problem as you guide them
16____present some problems (towards the end of the unit) that are formal by nature to promote continued cognitive development
17____encourage understanding of the concepts rather than rote parrotting of the facts
18____give "test conditions" worksheet problems toward end of unit

APPENDIX 2, PAGE 2

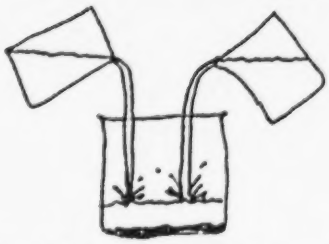
Specific notes on ways to improve those areas above that are not checked off:

APPENDIX 2, PAGE 3

Diagrams/ flowchart ideas:

# UNIT 7: Solids and Liquids
## An Overview

(a). Write balanced equation; remember... balancing numbers represent moles.
(b). If starting with gram value, convert to moles:
grams = moles
molar mass
(c). Calculate M amount as: moles per 1 liter of solution.



(d). After mixing, the volume doubled, and so the concentration is halved. (diluted)
(e). When the precipitate forms,
(1). 2 participator ions from the solutions join to form the precipitate,
(2). 2 spectator ions do not form a precipitate and remain unchanged,
(3). The precipitate continues to be formed until one or the other of the participator ions is used up. No more may then be made.

(a). Write balanced equation; remember... balancing numbers represent moles.
(b). If starting with gram value, convert to moles:
grams = moles
molar mass
(c). Calculate M amount as: moles per 1 liter of solution.

The participator ion that gets used up *first* is influenced by 2 factors: the amount of it available (based on the grams amount converted in the beginning of the problem), and its balancing number (which dictates how much of it is used compared to its partner in the formation of the precipitate).

Therefore, when given .3 mole of ion "A" and .1 mole of ion "B," it seems logical that if they form a precipitate, they will do so until "B" is used up (since there was so little of it to begin with). However, if it turns out that the balanced equation for the precipitate shows that they combine in a ratio of 6 "A" to 1 "B," this means that "A" may get used up sooner, since 6 moles of it are used for every 1 mole of "B" in the precipitate "recipe."

A formula can be used to keep all this straight (labels must match above & below):

$$\frac{\text{balancing number of one ion}}{\text{amount of moles of the ion you think was } \textit{all used up.}} = \frac{\text{balancing number of other ion}}{\text{amount (used up in the process)}}$$

Cross-multiply and solve for n, which provides the amount of the other ion that *was used up in the process.* Subtracting from the amount of moles when first combined gives the amount of it *left:*

$$\frac{6 \text{ "A"}}{.3 \text{ moles (all gone)}} = \frac{1 \text{ "B"}}{n}$$

n = .05 moles "B" *used*; $.1 - .05 = .05$ *left*

# APPENDIX 4

You are given 1.89 grams of $Zn(NO_3)_2$ dissolved in enough water to make a liter of solution, and you are also given 2 grams of NaOH dissolved in enough water to make a second 1 liter solution

a. write the equations showing the formation of the ions in each solution:

$$Zn(NO_3)_2 \rightarrow Zn^{+2} + 2NO_3^-$$

$$NaOH \rightarrow Na^+ + OH^-$$

b. how many moles of each ion are present?

$Zn(NO_3)_2$ $\frac{1.89\,g}{189\,g} = \frac{N\ mole}{1\ mole}$ $N = 0.01$ moles

.01 moles .01 .02

$Zn(NO_3)_2 \rightarrow Zn^{+2} + 2NO_3^-$

$NaOH$ $\frac{2g}{40g} = \frac{N\ mole}{1\ mole}$ $N = .05$ moles

.05 .05 .05

$NaOH \rightarrow Na^+ + OH^-$

c. what is the concentration (M) of each ion?

$$Zn^{+2} = \frac{.01}{1L} = .01M;\ NO_3^- = \frac{.02}{1L} = .02M;\ Na^+ = \frac{.05}{1L} = .05M;\ OH^- = \frac{.05}{1L} = .05M$$

d. what is the new concentration (M) of each ion after the two solutions are mixed?

$$Zn^{+2} = \frac{.01}{2L} = \frac{N}{1L} = .005M;\ NO_3^- = \frac{.02}{2L} = \frac{N}{1L} = .01M;\ Na^+ = \frac{.05}{2L} = \frac{N}{1L} = .025M;\ OH^- = \frac{.05}{2L} = \frac{N}{1L} = .025M$$

e. when $Zn^{+2}$ ion comes in contact with enough $OH^{-1}$ ion, $Zn(OH)_2$ (s) is formed

1. write the equation for the reaction between these <u>two</u> predominantly reacting species (net ionic)

$$Zn^{+2} + 2OH^- \rightarrow Zn(OH)_2\ (s)$$

2. write an equation to include all four ions and to show what happens to them during the reaction.

$$Zn^{+2} + 2NO_3^- + Na^+ + OH^- \rightarrow Zn(OH)_2(s) + NO_3^- + Na^+$$

3. indicate the concentration (M) of each ion remaining in the solution after the reaction has taken place

IN: OUT:

$Zn^{+2} + 2NO_3^- + Na^+ + OH^- \rightarrow$ $2NO_3^- + Na^+ + Zn^{+2} + OH^-$

.005M .01M .025M .025M <u>.01M</u> <u>.025M</u> <u>NONE</u> $.025M - 2(.005)M = .015\ M$ left

needed for $Zn(OH)_2(s)$

REMEMBER: Concentration means Molarity (M) which means

<u>moles of a substance dissolved (solute)</u>
in 1 liter (or, 1000 ml) of solution (dissolved substance <u>plu</u> water)

# APPENDIX 5

UNIT VII WORK SHEET #3

I. 17.1 grams of $Ba(OH)_2$ are dissolved in enough water to make 1 liter of solution. 28.4 grams of $Na_2SO_4$ are dissolved in another quantity of water to make 1 liter of solution.

a. write the equations showing the formation of the ions in each solution.
b. how many moles of each ion are present?
c. what is the concentration (M) of each ion?
d. what is the new concentration (M) after the two solutions are mixed?
e. when $Ba^{+2}$ ion comes in contact with enough $SO_4^{-2}$ ion, $BaSO_4$ (s) is formed.
   1. write the equation for the reaction between these two predominantly reacting species.
   2. write an equation to include all four ions and to show what happens to them during the reaction.
   3. indicate the concentration (M) of each ion remaining in the solution after the reaction has taken place.

II. 32.5 grams of $FeCl_3$ are made into 1 liter of solution; and 16.8 grams of K OH are made into 1 liter of another solution.

answer all of the questions asked in (I) but in this case $Fe^{+3}$ and $OH^{-1}$ form $Fe(OH)_3$ (s)

III. 1.06 grams of $Na_2CO_3$ are made into 1 liter of solution; and 6.39 grams of $Al(NO_3)_3$ are made into another 1 liter solution.

answer all of the questions asked in (I) but in this case $Al^{+3}$ ions and $CO_3^{-2}$ ions form $Al_2(CO_3)_3$ (s).

IV. 2.76 grams of $Ag_2CO_3$ are made into 1 liter of solution; and 1.36 grams of $(NH_4)_2$ S are made into another 1 liter solution.

answer all of the questions asked in (I) but in this case $Ag^+$ ions and $S^{-2}$ ions form $Ag_2S$ (s).

# APPENDIX 6

## CHEMISTRY

## STUDENT EVALUATION OF UNIT/CHAPTER

UNIT/ CHAPTER

TITLE_____ UNIT/

CHAPTER NUMBER_____ DATE_____

COURSE_____

The following unit/chapter evaluation will be used to better plan various aspects of this course for students who enroll in it in the future. Please answer the questions seriously.

1. On a scale of 1 to 5, rate yourself on how well you completed all of the daily assignments in this unit. Do not count assignments that were copied from others or were copied off the overhead transparencies/ chalkboard (1 being little completed, 5 being all completed):

1 2 3 4 5

2. If you responded "4" or less to the above question, please give a brief reason:

_____

3. Do you feel that there is something that the teacher can do to improve your response to question #1 above?_____ If "yes," please comment further:

_____

4. On a scale of 1 to 5, rate yourself on how hard you worked at straightening out something that you didn't understand in this unit, such as by asking the teacher to explain it again, asking another student to explain it, or coming in to get extra help from the teacher after school
(1 being little effort, 5 being much effort):

1 2 3 4 5

5. If you responded "4" or less to the above question, please give a brief reason:

_____

6. Do you feel that there is something that the teacher can do to improve your response to question #4 above?_____ If "yes," please comment further:

_____

_____

7. How well do you feel you were able to understand the concepts presented in this unit? (1 being not well at all, 5 being very well):

1 2 3 4 5

8. How well do you feel the teacher made an effort to explain the concepts of the unit to you in terms you could understand? (1 being not well, 5 being very well):

1 2 3 4 5

9. Was there a specific style of problem in this unit that you couldn't manage to understand, even though you tried to?

_____ If "yes," please state the type of problem as best you can:_____

_____

10. Seriously, what characteristics do you feel a course/the teacher should have in order for you to feel that the hours spent enrolled in it are worthwhile? Please try to be as specific as possible.

_____

_____

_____

_____

_____

11. Assuming that you had to be exposed to the concepts of this chapter/ unit no matter what, and that you made a decent effort to learn the concepts, do you feel that the hours you spent attending this class <u>were</u> worthwhile?

_____ Please comment further, including suggestions for making this chapter/unit more worthwhile for students

taking this course in the future. Use more space if necessary. Thank you for your cooperation.

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